N Sub B1

P N K

~~1. A device for detecting a specific material that may be present in an ensemble of objects comprising means to expose an area of the ensemble to x-ray energies to produce dual energy image information of the ensemble and means to computer-process such dual energy information to detect said specific material on the basis of comparisons of selected subareas of said exposed area to other subareas in the vicinity of said selected subareas.~~

~~2. A device for detecting a bomb that may be present in a container of objects comprising means to expose an area of the container to x-ray energies to produce dual energy image information of the container and its contents and means to computer-process such dual energy information to detect said bomb on the basis of comparisons of selected subareas of said exposed area to other subareas in the vicinity of said selected subareas.~~

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3. A device for detecting a specific material that may be present in an ensemble of objects comprising means to expose an area of the ensemble to x-rays of at least two substantially different energy bands to produce dual energy image information of the ensemble and means to computer-process such dual energy information to detect said specific material on the basis of comparisons between attenuation image information from at least one of said energy bands and positionally corresponding image information of parameter P values derived from correlations of said dual energy image information with values in a predetermined lookup table reflecting attenuation at high and low energy bands over a range of thicknesses of a selected specific material and a range of thicknesses of a representative overlay material, with attenuation of a constant thickness of said overlay

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material and varying thicknesses of said specific material represented by said parameter P.

~~4.~~ 4 The device of claim ~~3~~ 3 wherein the means to computer-process includes means for evaluating gradients of values in at least one of the images.

~~5.~~ 5 The device of claim ~~4~~ 4 wherein the means to computer-process includes means for evaluating gradients of values in both said attenuation image and said image of P values.

~~6.~~ 6 The device of claim ~~4~~ 4 having means for selecting the regions of said attenuation image information for said comparisons on the basis of the steepness of gradients of attenuation values in said attenuation image.

D ~~7.~~ 7 The device of claim ~~4, 5 or 6~~ 6 wherein said means for selecting employs an edge finding operator.

~~8.~~ 8 The device of claim ~~6~~ 6 including means for generating gradient values H_s for substantially all subareas

H and means for pruning to remove subareas with H_s values below a selected threshold, and means for thereafter

L H performing said comparisons using the remaining H_s values.

~~9.~~ 9 A device for detecting and indicating the probable presence of a specific material in an ensemble of objects, comprising

R1 means for exposing said item to x-rays of at least two substantially different energy levels,

means for generating for each subarea over the exposed area a set of data values representing logarithms of x-ray attenuation at said subarea at each of said energy levels,

means for processing said data for said subarea to compute the values of (H,L) for said subarea, wherein H is the logarithm of the attenuation of said x-rays at said subarea at the higher energy level and L is the logarithm of the attenuation of said x-rays at said subarea at the lower energy level, and

means for applying an edge finding or gradient evaluating operator such as a Sobel operator to image data of at least one energy level,

means for generating gradient values H_s for substantially all subareas,

means for pruning to remove subareas with gradient values H_s below a selected gradient threshold,

means for determining for remaining subareas with gradient values H_s above said selected gradient threshold parameter P values using a lookup table in computer storage reflecting x-ray attenuation at high and low energy bands over a range of thicknesses of said selected specific material and a range of thicknesses of a representative overlay material, with attenuation of a constant thickness of said overlay material and varying thicknesses of said specific material represented by said parameter P,

means for applying said gradient evaluating operator to P image data formed using said parameter P values for said remaining subareas,

means for generating gradient values P_s for said remaining subareas,

means for calculating a ratio H_s/P_s for said remaining subareas,

means for raising said ratio to a power at least as large as unity to emphasize large values of said ratio, and

means for storing said ratio H_s/P_s raised to said power for substantially all of said remaining subareas.

10. The device of claim 9 further comprising

means for selecting an alarm threshold on said ratio H_s/P_s raised to said power so that subareas having said ratio H_s/P_s raised to said power above said alarm threshold are strongly indicative of presence of said specific material,

means for applying a dilation algorithm using said H values and said L values for said image data,

means for sounding an alarm if a certain number of subarea values are above said alarm threshold,

means for applying an erosion algorithm to eliminate spurious noise in said image data, and

means for displaying said image data with areas of particular interest highlighted.

11. A device for detecting and indicating the probable presence of a specific material in an ensemble of objects, comprising

means for exposing said item to x-rays of at least two substantially different energy levels,

means for generating for each subarea over the exposed area a set of data values representing logarithms of x-ray attenuation at said subarea at each of said energy levels,

means for filtering said data for said subarea,

means for averaging said data for said subarea,

means for processing said data for said subarea to compute the values of (H,L) for said test subarea, wherein H is the logarithm of the attenuation of said x-rays at said subarea at the higher energy level and L is the logarithm of the attenuation of said x-rays at said subarea at the lower energy level, and

means for applying an edge finding or gradient evaluating operator such as a Sobel operator to image data of at least one energy level,

means for generating gradient values H_s for substantially all subareas,

means for pruning to remove subareas with gradient values H_s below a selected gradient threshold,

means for determining for remaining subareas with gradient values H_s above said selected gradient threshold parameter P values using a lookup table in computer storage reflecting x-ray attenuation at high and low energy bands over a range of thicknesses of said selected specific material and a range of thicknesses of a representative overlay material, with attenuation of a constant thickness of said overlay material and varying thicknesses of said specific material represented by said parameter P,

means for applying said gradient evaluating operator to P image data formed using said parameter P values for said remaining subareas,

means for generating gradient values P_s for said remaining subareas,

means for calculating a ratio H_s/P_s for said remaining subareas,

means for raising said ratio to a power at least as large as unity to emphasize large values of said ratio,

means for storing said ratio H_s/P_s raised to said power for substantially all of said remaining subareas,

means for selecting an alarm threshold on said ratio H_s/P_s raised to said power so that subareas having said ratio H_s/P_s raised to said power above said alarm threshold are strongly indicative of presence of said specific material,

means for applying a dilation algorithm using said H values and said L values for said image data,

means for sounding an alarm if a certain number of subarea values are above said alarm threshold,

means for applying an erosion algorithm to eliminate spurious noise in said image data, and

means for displaying said image data with areas of particular interest highlighted.

12. A device for inspecting an ensemble of physical objects comprising means to expose an area of said ensemble to x-rays of at least two substantially different energy bands, detection means responsive to said x-rays passing through said ensemble to generate for subareas over said area respective sets of values representing the attenuation of said x-rays at each of said energy bands, comparison means operative on differences in attenuation between subareas in a neighborhood to determine the presence of a specific material in the neighborhood, and indicating means responsive to said comparisons for indicating presence of said specific material in said ensemble.

13. The device of claim 12 wherein said comparison means includes a lookup table reflecting attenuation at high and low energy bands over a range of thicknesses of a

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selected specific material and a range of thicknesses of a representative overlay material, with attenuation of a constant thickness of said overlay material and varying thicknesses of said specific material represented by a parameter P.

32 ~~14~~. The device of claim ~~13~~ 12 including means to reference actual attenuation measurements of subareas at an energy band with parameter P values for said subareas, and using said determination in determining the presence of said specific material.

Sub B2

15. The device of claim 12 wherein said comparison means include means to combine, according to a predetermined formula, values representing the attenuation of said x-rays for subareas in said neighborhood to provide an attenuation measure and means to compare said measure to a reference related to said specific material.

16. The device of claim 12 wherein said values generated representing the attenuation of said x-rays at said energy bands are logarithms of x-ray attenuation at each of said energy bands at each subarea.

17. The device of claim 12 wherein said comparison means comprises means for computing for a selected test subarea of said area the values (H_T,L_T) wherein H_T is the logarithm of the attenuation of said x-rays at said higher energy band at said test subarea and L_T is the logarithm of the attenuation of said x-rays at said lower energy band at said test subarea, means for computing for a subarea nearby said test subarea the values (H_B,L_B) wherein H_B is the

Claims 33-35

100

logarithm of the attenuation of said x-rays at said higher energy band at said nearby subarea and L_B is the logarithm of the attenuation of said x-rays at said lower energy band at said nearby subarea, said comparison means constructed to employ said values (H_T,L_T) ~~and~~ (H_B,L_B) in determining the presence of said specific material.

~~18.~~ 25. The device of claim ~~17~~ 24, further comprising means for providing p-values P representing attenuation characteristics of various overlying materials, means for associating a p-value P_T with said values (H_T,L_T) wherein said p-value P_T is proportional to the thickness of overlying materials at said test subarea, means for associating a p-value P_B with said values (H_B,L_B) wherein said p-value P_B is proportional to the thickness of overlying materials at said nearby subarea, means for computing the value of $|(H_T-H_B)/(P_T-P_B)| = \Delta H/\Delta P$ and means for associating $\Delta H/\Delta P$ with a relative probability measure for the presence of said specific material at respective subareas.

~~19.~~ 26. The device of claim ~~18~~ 25 wherein the relative probability measure is proportional to $(\Delta H/\Delta P)^q$, wherein q is a value chosen to emphasize extrema of the value of $\Delta H/\Delta P$.

~~20.~~ 27. The device of claim ~~19~~ 26 wherein q=2.

~~21.~~ 28. The device of claim ~~18~~ 25 wherein said means for associating a p-value P with said values (H,L) involves identifying said values with respective points from a set of points previously generated by numerically varying

thicknesses of said specific material and said overlying materials.

29 ~~28~~ ~~22~~. The device of claim 24 ~~20~~ ~~17~~ wherein said comparison means comprises means for computing the value of $(H_T-H_B)/(L_T-L_B) = K_{TB}$ and means for comparing said value of K_{TB} with the value of K_{MAT} wherein K_{MAT} is an attenuation characteristic of said specific material.

H31

H

30 ~~29~~ ~~23~~. The device of claim 29 ~~28~~ ~~22~~ wherein K_{MAT} is a stored value developed by prior measurements.

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31 ~~30~~ ~~24~~. The device of claim 29 ~~28~~ ~~22~~ wherein $K_{MAT} \approx \mu_H/\mu_L$ wherein μ_H is the attenuation coefficient of said specific material exposed to said higher energy band x-rays and μ_L is the attenuation coefficient of said specific material exposed to said lower energy band x-rays.

H,167,82

82H

Sub B4

25. The device of claim 12 further comprising means for exposing selected numbers of samples of various known materials each of a range of different thicknesses to said x-rays of said different energy bands to measure the attenuation characteristic of the exposed samples to provide a reference for said comparison means.

IB

33 ~~32~~ ~~26~~. The device of claim 32 ~~40~~ ~~25~~ including calculation means for interpolating between said measured values to estimate intermediate values for use in making said comparison.

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Sub B5

27. The device as in any of claims 3-26 further comprising means for assigning to subareas over said exposed

IB

area of the object relative probabilities for the presence of said specific material based upon said comparisons, said indicating means being responsive to said relative probability assignments for indicating presence of said specific material in said object.

36 ~~28~~. A baggage inspection device for detecting and indicating the probable presence of a specific material in an item of baggage comprising means to expose an area of said item to x-rays of at least two substantially different energy bands, detection means responsive to said x-rays passing through said item to generate for subareas over said area respective sets of values representing the attenuation of said x-rays at each of said energy bands, comparison means operative on differences in attenuation between subareas in a neighborhood to determine the presence of a specific material in the neighborhood of said subareas, and indicating means responsive to said comparisons for indicating presence of said specific material in said item, said comparison means comprising means for computing for a selected test subarea of said area the values (H_T, L_T) wherein H_T is the logarithm of the attenuation of said x-rays at said higher energy band at said test subarea and L_T is the logarithm of the attenuation of said x-rays at said lower energy band at said test subarea, means for computing for a subarea nearby said test subarea the values (H_B, L_B) wherein H_B is the logarithm of the attenuation of said x-rays at said higher energy band at said nearby subarea and L_B is the logarithm of the attenuation of said x-rays at said lower energy band at said nearby subarea, said comparison means constructed to employ said values

H

(H_T, L_T) and (H_B, L_B) in determining the presence of said specific material.

~~29~~ 37. The device of claim ~~28~~ 36 wherein said comparison means comprises

P1 P1 H L H L

means for providing p-values P representing attenuation characteristics of various overlying materials,

means for associating a p-value P_T with said values (H_T, L_T) wherein said p-value P_T is proportional to the thickness of overlying materials at said test subarea, means for associating a p-value P_B with said values (H_B, L_B) wherein said p-value P_B is proportional to the thickness of overlying materials at said nearby subarea, means for computing the value of $|(H_T-H_B)/(P_T-P_B)| = \Delta H/\Delta P$ and means for associating $\Delta H/\Delta P$ with a relative probability measure for the presence of said specific material at respective subareas.

51, H, 31, 66, 66,

~~30~~ 38. The device of claim ~~13~~ 12, ~~14~~ 32, ~~18~~ 25 or ~~29~~ 37, including

P1 L P1 L

means for examining said subareas,

means responsive thereto for producing values for each subarea indicative of the relative probability of matching said specific material,

means for displaying subareas over said area, and

means for highlighting those subareas having a probability greater than or equal to a selected threshold value of matching said specific material.

~~31~~ 39. The device of claim ~~28~~ 36 wherein said comparison means comprises means for computing the value of

H 31

$(H_T-H_B)/(L_T-L_B) = K_{TB}$ and means for comparing said value of

H K_{TB} with the value of K_{MAT} wherein K_{MAT} is an attenuation characteristic of said specific material.

H 82H 82H ~~32~~ 40. The device of claim ~~17~~ 24 or ~~28~~ 36, wherein $K_{MAT} = \mu_H(H_T, L_T, H_B, L_B)/\mu_L(H_T, L_T, H_B, L_B)$ wherein μ_H is an attenuation coefficient of said specific material exposed to said higher energy x-rays, comprising a function of the logarithms of the attenuation of said x-rays at said test subarea and at said nearby subarea, wherein μ_L is an attenuation coefficient of said specific material exposed to said lower energy x-rays, comprising a function of said logarithms of the attentuation of said x-rays at said test subarea and at said nearby subarea.

P1H L ~~33~~ 41. The device of claim ~~32~~ 40 including

means for ascertaining whether said value of K_{TB} is within a selected window of values of K_{MAT},

P1 means for incrementing a respective counter if said value of K_{TB} is within said window,

H P1 means for examining said subarea counters and producing values for each subarea indicative of the relative probability of matching said specific material,

P1 L means for displaying subareas over said area, and

means for highlighting those subareas having a probability greater than or equal to a selected threshold value of matching said specific material.

NP Sub B6 NK 34. The device of claim 1, 2, 3 or 12 wherein said means to expose said area further comprises an x-ray source, means for generating from said source x-rays of at least two substantially different energy bands, means for collimating

N

a fan beam of said x-rays, and means for conveying said object to intercept said fan beam of said x-rays.

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35. The device of claim 12, wherein said indicating means is a visual display of an x-ray image, and said indication being of the form of distinguished subareas at which the specific material is probably present.

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36. The device of claim 1, 2, 3, 12 or 28, wherein said specific material is a threatening substance.

43 ~~37~~. The device of claim 36, wherein said threatening substance is an explosive.

K Sub B7

38. The device of claim 1, 2, 3, 12 or 28, wherein said specific material is an illicit drug substance.

B

39. The device of claim 1, 3 or 12, wherein said ensemble comprises components of a stream of matter.

18 ~~40~~. The device of claim 17 ~~39~~, wherein said stream is comprised of rocks and other materials, and said specific material is a mineral of value.

19 ~~18~~ ~~41~~. The device of claim 17 ~~39~~, wherein said stream is shredded plastic refuse, and said specific material is a particular form of plastic.

20 ~~42~~. The device of claim 19 ~~41~~, wherein said particular form of plastic comprises halogenated hydrocarbon plastic to be separated from other plastic refuse.

Claim 21

Sub B8

43. The device of claim 1, 3 or 12, wherein said ensemble comprises foodstuffs.

22 ~~44.~~ The device of claim 21 ~~43~~, wherein said foodstuffs are meat, and wherein said specific material is bone.

23 ~~45.~~ The device of claim 21 ~~43~~, wherein said specific material is inorganic.

Sub B9

46. The device of claim 1 or 2 further comprising means for locating edges in the exposed area where one material overlaps another, means for choosing subareas in close proximity to said edges to be said selected subareas, and means for assigning to said selected subareas a relative probability for the presence of said specific materials at said subareas based upon said comparisons with other subareas in the vicinity, and indicating means responsive to said relative probability assignment.

47. The device of claim 12 further comprising means for locating edges in the exposed area where one material overlaps another, means for choosing subareas in close proximity to said edges to be said selected subareas, and means for assigning to said selected subareas a relative probability for the presence ~~of said~~ specific materials at said subareas based upon comparisons with other subareas in the neighborhood, said indicating means being responsive to said relative probability assignment.

48. The device of claim 1, 2, 12, 46 or 47 further comprising means for dilating indications of subareas over regions whose edges have been determined to indicate the presence of said specific material, wherein said dilation

Claim 24

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makes said regions more prominently noticeable to an operator of said device, and wherein said dilation enhances indication of presence of said specific material.

49. A method of detecting a specific material that may be present in an ensemble of objects comprising exposing an area of the ensemble to x-ray energies to produce dual energy image information of the exposed ensemble and computer-processing such dual energy information to detect said specific material on the basis of comparisons of selected subareas of said exposed area to other subareas in the vicinity of said selected subareas.

50. A method of detecting a bomb that may be present in a container of objects comprising exposing an area of the container to x-ray energies to produce dual energy image information of the exposed container and computer-processing such dual energy information to detect said bomb on the basis of comparisons of selected subareas of said exposed area to other subareas in the vicinity of said selected subareas.

50 ~~51~~. A method of baggage inspection for detecting and indicating the probable presence of a specific material in an item of baggage, comprising the steps of

exposing said item to x-rays of at least two substantially different energy levels,

generating for each subarea over the exposed area a set of data values representing logarithms of x-ray attenuation at said subarea at each of said energy levels,

choosing a test subarea,

filtering said data for said test subarea,

averaging said data for said test subarea,

processing said data for said test subarea to compute the values of (H_T, L_T) for said test subarea, wherein H_T is the logarithm of the attenuation of said x-rays at said test subarea at the higher energy level and L_T is the logarithm of the attenuation of said x-rays at said test subarea at the lower energy level, and

choosing a background subarea,

filtering said data for said background subarea,

averaging said data for said background subarea,

processing said data for said background subarea to compute the values of (H_B, L_B) for said background subarea, wherein H_B is the logarithm of the attenuation of said x-rays at said background subarea at the higher energy level and L_B is the logarithm of the attenuation of said x-rays at said background subarea at the lower energy level, and

computing the value of $K_{TB} = (H_T - H_B)/(L_T - L_B)$, and

comparing said value of K_{TB} to the value of K_{MAT}, wherein $K_{MAT} = \mu_H(H_T, L_T, H_B, L_B)/\mu_L(H_T, L_T, H_B, L_B)$ wherein μ_H, an attenuation coefficient of a specific material exposed to said higher energy x-rays, is a function of the logarithms of the attenuation of said x-rays at said test subarea and at said background subarea, wherein μ_L, an attenuation coefficient of said specific material exposed to said lower energy x-rays, is a function of the logarithms of the attenuation of said x-rays at said test subarea and at said background subarea, and

ascertaining whether said value of K_{TB} is within a selected window of values of K_{MAT}, incrementing a respective counter if said value of K_{TB} is within said window,

choosing another background subarea, and

iterating the steps from filtering said data for said background subarea to choosing another background

subarea until a substantial number of background subareas have been so examined, and

choosing another test subarea, and

iterating the steps from filtering said data for said test subarea to choosing another test subarea until substantially all subareas have been so tested, and

examining said subarea counters,

producing values for each subarea indicative of the relative probability of matching said specific material, and

displaying subareas over said area, and

highlighting those subareas having a probability greater than or equal to a selected threshold value of matching said specific material.

51 ~~52~~. A method of baggage inspection for detecting and indicating the probable presence of a specific material in an item of baggage, comprising the steps of

exposing said item to x-rays of at least two substantially different energy levels,

generating for each subarea over the exposed area a set of data values representing logarithms of x-ray attenuation at said subarea at each of said energy levels,

choosing a test subarea,

filtering said data for said test subarea,

averaging said data for said test subarea,

processing said data for said test subarea to compute the values of (H_T, L_T) for said test subarea, wherein H_T is the logarithm of the attenuation of said x-rays at said test subarea at the higher energy level and L_T is the logarithm of the attenuation of said x-rays at said test subarea at the lower energy level, and

choosing a background subarea,

filtering said data for said background subarea,

averaging said data for said background subarea,

processing said data for said background subarea to compute the values of (H_B, L_B) for said background subarea, wherein H_B is the logarithm of the attenuation of said x-rays at said background subarea at the higher energy level and L_B is the logarithm of the attenuation of said x-rays at said background subarea at the lower energy level, and

providing p-values P representing attenuation characteristics of various overlying materials,

associating a p-value P_T with said values (H_T, L_T) wherein said p-value P_T is proportional to the thickness of overlying materials at said test subarea,

associating a p-value P_B with said values (H_B, L_B) wherein said p-value P_B is proportional to the thickness of overlying materials at said nearby subarea,

computing the value of $|(H_T-H_B)/(P_T-P_B)| = \Delta H/\Delta P$,

associating $\Delta H/\Delta P$ with a relative probability measure for the presence of said specific material at respective subareas,

storing said probability measure,

choosing another background subarea, and

iterating the steps from filtering said data for said background subarea to choosing another background subarea until a substantial number of background subareas have been so examined, and

choosing another test subarea, and

iterating the steps from filtering said data for said test subarea to choosing another test subarea until substantially all subareas have been so tested, and

examining said subarea probability measure stores,

producing values for each subarea indicative of the relative probability of matching said specific material, and

displaying subareas over said area, and

highlighting those subareas having a probability greater than or equal to a selected threshold value of matching said specific material.

52 ~~53~~. A method of detecting a specific material that may be present in an ensemble of objects comprising the steps of

exposing an area of the ensemble to x-rays of at least two substantially different energy bands to produce dual energy image information of the ensemble, and

computer-processing such dual energy information to detect said specific material on the basis of comparisons between attenuation image information from at least one of said energy bands and positionally corresponding image information of parameter P values derived from correlations of said dual energy image information with values in a predetermined lookup table reflecting attenuation at high and low energy bands over a range of thicknesses of a selected specific material and a range of thicknesses of a representative overlay material, with attenuation of a constant thickness of said overlay material and varying thicknesses of said specific material represented by said parameter P.

53 ~~54~~. A method of detecting and indicating the probable presence of a specific material in an ensemble of objects, comprising the steps of

exposing said item to x-rays of at least two substantially different energy levels,

generating for each subarea over the exposed area a set of data values representing logarithms of x-ray attenuation at said subarea at each of said energy levels,

filtering said data for said subarea,

averaging said data for said subarea,

processing said data for said subarea to compute the values of (H,L) for said test subarea, wherein H is the logarithm of the attenuation of said x-rays at said subarea at the higher energy level and L is the logarithm of the attenuation of said x-rays at said subarea at the lower energy level, and

applying an edge finding or gradient evaluating operator such as a Sobel operator to image data of at least one energy level,

generating gradient values H_s for substantially all subareas,

pruning to remove subareas with gradient values H_s below a selected gradient threshold,

determining for remaining subareas with gradient values H_s above said selected gradient threshold parameter P values using a lookup table in computer storage reflecting x-ray attenuation at high and low energy bands over a range of thicknesses of said selected specific material and a range of thicknesses of a representative overlay material, with attenuation of a constant thickness of said overlay material and varying thicknesses of said specific material represented by said parameter P,

applying said gradient evaluating operator to P image data formed using said parameter P values for said remaining subareas,

generating gradient values P_s for said remaining subareas,

calculating a ratio H_s/P_s for said remaining subareas,

raising said ratio to a power at least as large as unity to emphasize large values of said ratio,

storing said ratio H_s/P_s raised to said power for substantially all of said remaining subareas,

selecting an alarm threshold on said ratio H_s/P_s raised to said power so that subareas having said ratio H_s/P_s raised to said power above said alarm threshold are strongly indicative of presence of said specific material,

applying a dilation algorithm using said H values and said L values for said image data,

sounding an alarm if a certain number of subarea values are above said alarm threshold,

applying an erosion algorithm to eliminate spurious noise in said image data, and

displaying said image data with areas of particular interest highlighted.

55. The method as in any of claims 49-54 further comprising employing computed tomographic information to detect said specific material that may be present in subareas indicated by said computer-processed dual energy information as being probable subareas for the presence of said specific materials.

56. For use in detecting a specific material that may be present in an area being exposed to x-ray energies, a lookup table in computer storage reflecting x-ray attenuation at high and low energy bands over a range of thicknesses of said selected specific material and a range of thicknesses of a representative overlay material, with

Claim 54

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attenuation of a constant thickness of said overlay material and varying thicknesses of said specific material represented by a parameter P.

Add B11